SEASONAL RELATIONSHIPS OF PREDATOR ASSEMBLAGES AND THEIR PREY, *THRIPS TABACI* LINDEMAN, IN MONOCULTURE AND POLYCULTURE ONION SYSTEMS

A Thesis

Presented to the Faculty of the Graduate School

Of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Master of Science

By

Elaine Josephine Fok

August 2013

ABSTRACT

Pest management can may be enhanced by vegetational diversity in agroecosystems through complementary top-down or bottom-up mechanisms, elucidated by the enemies hypothesis or the resource concentration hypothesis, respectively. In many cases, populations of natural enemies benefit from diversification strategies, but this may not always lead to increased biological control of the pest. The impact that vegetational diversity has on predator diversity and abundance in onion ecosystems in New York State is not well understood.

Onions are grown in monoculture and polyculture production systems in New York with habitat diversity being greater in onion ecosystems grown in polyculture than in monoculture. In New York, *T. tabaci* is the most damaging insect pest of onion and the only significant foliar pest. Severe infestations can reduce bulb size by up to 60%; however, the threshold of economic injury is difficult to assess because damage is typically not directly done to the onion bulb. The overall goals of this research were: assess naturally occurring populations of predators in onions grown in monoculture and polyculture systems by identifying the predators of *T. tabaci* and their relative abundance in the two types of onion production systems in New York; describe the temporal patterns of the predator and *T. tabaci* populations in these onion fields, and; and explore to what extent predator abundance can be predicted by *T. tabaci* abundance within the two onion production systems.

Research was conducted in major onion-producing regions in Central and Western New York in 2011 and 2012. Each onion production site was classified as

either a monoculture or polyculture. Predator diversity and abundance, as well as *T. tabaci* abundance, were assessed in onion fields grown following commercial production practices as well as in small, non-insecticide treated plots. All predators and *T. tabaci* larvae were visually counted and recorded in both grower-managed fields and insecticide-free plots in monoculture and polyculture systems. Sticky cards were also used to assess predator populations. Data were analyzed separately by year. Predator abundance in each taxonomic group was very low and precluded robust comparisons. Thus, for all data analyses pertaining to predator counts, total numbers of predators rather than each taxonomic group of predators were analyzed.

Our study found that predator populations benefit from vegetational diversity, which is consistent with the enemies hypothesis that predicts a positive correlation between plant species richness and natural enemy abundance. We encountered more predators in polyculture sites compared to monoculture sites, which is likely due to vegetational diversity because thrips populations were not significantly different between systems. We observed a predator complex of four families and seven genera in both monoculture and polyculture onion production systems in New York State. Predators were found to be positively correlated with thrips, even at low densities. The positive relationship between predators and thrips was furthermore significant in both monoculture and polyculture insecticide-free plots in 2011. In polyculture insecticide-free plots, however, other resources such as alternate prey, pollen, and shade are potentially available to predators in addition to

thrips prey. While thrips significantly contribute to predator populations, it is likely that other resources are also supporting predator populations.

Many efforts have been made in the pest management of *T. tabaci* over the last several decades. Previous research has found that systems typically lack appropriate natural enemies, and the native complex is likely insufficient for control. However, some evidence of cultural controls, such as intercropping, have shown promise for future thrips management strategies. Diversification strategies in onion agroecosystems will likely foster the development of natural enemy populations, which could contribute to future management strategies of thrips pest populations.

BIOGRAPHICAL SKETCH

Elaine Fok was born July 18, 1987 in Livermore, CA and grew up steeped in the cultural and culinary diversity of the San Francisco Bay Area. She graduated from Foothill High School in 2005 and went on to study Environmental Science at the University of California Berkeley. During her senior year at Cal, she began digging around in urban agriculture and food politics. After graduating with a B.S. in Environmental Science in 2009, she turned her attention to sustainable agriculture and began working as field research coordinator for the Agroecology Research Group with Dr. Miguel Altieri. With other self-proclaimed foodies and ecologists, she investigated conservation biological control and floral resource provisioning in California vineyards. It was among the wine grapes that she fell in love with insects and decided to pursue graduate studies in Entomology at Cornell University under Dr. Brian Nault. As she finished her Masters' Degree, Elaine began working as Program Coordinator at the Yolo Food Bank in Woodland, CA. In the agricultural hub of Northern California, she continues to share her passion for food and sustainability through the Kid's Farmers Market program.

DEDICATION

This manuscript is dedicated to my niece

Audrey McNinch

for her curiosity to find out “where buggy-bug from-from.”

ACKNOWLEDGEMENTS

I thank my advisor, Dr. Brian Nault, for his guidance, enthusiasm, and support throughout my graduate career. I would also like to thank my committee members, Drs. Jan Nyrop, Anthony Shelton, and Jennifer Thaler for their input and suggestions throughout the research process.

In addition, I would like to thank Dr. Jessica Petersen for her helpful suggestions, advice, support, and her invaluable friendship. This work could not have been completed without the assistance of Erik Smith, Mary Lou Hessney, Katie Cappiello, Martin Holdrege, and numerous other summer workers.

My graduate experience was greatly enhanced by my fellow mouse-mates at Stewart Little Co-op, and the enthusiasm of Joanna Fisher, Jacqueline Dillard, Erin Morris, and Maria Carrizales. In the final stretch, Tim Lander kept me motivated and forbade me "to get any other ideas."

Lastly, I would like to thank the Department of Entomology and the New York State Agricultural Experiment Station for funding my research and the numerous opportunities to be involved with the academic community and educational outreach.

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INTRODUCTION

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A. Economic importance

Of the twenty genera in the subfamily Allioideae (Amaryllidaceae), *Allium* is the most economically important. Crops include garlic (*A. sativum*), shallot (*A. oschaninii*), leek (*A. ampeloprasum*), chive (*A. schoenoprasum*) and onion (*A. cepa*). Dry bulb onion is the most cultivated *Allium* crop worldwide. Onion was most likely domesticated in the mountainous regions of southwest Asia over 4700 years ago (Brewster 2008). A biennial crop, onion is harvested as a bulb after the first growing season, while the seeds are harvested after the second growing season when onion is fully mature. Due to the ease of storage and transportation, international trade of onion is prominent. The value of dry bulb onion production was ranked 15th worldwide in 2010 (*FAOSTAT* 2012). In particular, the United States is a major player as the 4th largest importer of onion in 2010. Furthermore, the U.S. ranked 3rd in the world for onion production with one of the highest yields worldwide, producing over 3.3 million tonnes and grossing over $700 million.

B. Production In New York State

Dry bulb onion is one of the most valuable vegetable crops in New York State, which ranked 5th in the nation for production and grossed $53 million in 2010 with 10,200 acres of onion harvested (*USDA Economic Research Service* 2011).

Throughout the state, onions are grown primarily on muck soils. Muck soils are quite fertile and retain moisture well. Furthermore, muck soils have a loose texture and are thus ideal for growing onions, among other root and tuber crops (Knott 1930). In New York, 30,091 acres of muckland were used for growing crops in 2010, with 8,825 acres of onion production across the state (*USDA National Agricultural Statistics Service* 2010). Other vegetables grown on muck include leafy vegetables, cucurbits, cruciferous crops, potatoes, sweet corn, and carrots. The largest commercial onion growing region in New York is located in Orange County, which lies in the southwestern part of the state, and includes 2,687 acres of onions. The second largest commercial onion producing region is in the Elba muck region in Orleans and Genesee Counties in Upstate New York with 2,580 acres of onions. Onions also are grown in smaller pockets of muck soil ranging from 200 to 1,000 planted acres in Oswego, Madison, Oneida, Ontario, Steuben, Yates, and Wayne Counties. The remaining onion crop is grown on non-muck land on small farms for produce auctions, farmers markets, farm stands, and community-supported agriculture (CSA) shares (*Cornell Vegetable Program* 2012).

Habitats in these onion agroecosystems are vastly different depending on the scale at which onions are grown. Onions on muck soils are typically grown in monoculture where individual fields may be partitioned in 5 to 10 acre blocks, often separated by willow windbreaks, but are contiguous and span hundreds of acres or more. Less than 5% of onion fields on muck are rotated in New York (Larentzaki et al. 2007) because muck is premium land for producing onions. In contrast, onions grown on non-muck land are planted in fields ranging in size from <0.1 to 2 acres on

small-diversified polyculture farms with multiple crops growing in adjacent fields. The size of onion production on these farms is highly variable. Thus, the habitat diversity in onion ecosystems varies with large and small-scale production.

Most onions are directly sown in the field between late March and mid May. While direct seeding is the most economical method of planting, onions germinate slowly and are fragile at emergence. To minimize stand loss, barley (*Hordeum vulgare* L.) is typically planted in rows alongside onion or broadcast seeded throughout the field. Barley germinates more quickly than onion and protects onion seedlings by serving as a windbreak, reducing seedling loss due to high winds and preventing soil erosion (Stivers 1999). Once the onion stand is established, the barley is treated with a grass-selective herbicide to prevent competition between the onion crop and barley and facilitate onion production for the remainder of the season.

Transplanting of onion seedlings occurs in approximately 10-15% of onion growing acreage in April and May (Nault et al. 2008). Most commercial growers in New York plant bare-root transplants that have been grown initially in California, Arizona, and Texas. These transplants are then pulled, packaged and sent to New York via refrigerated trucks. Transplanted onions typically reach maturity earlier than their direct-seeded counterparts and growers often choose this option to increase bulb size and profits (Stivers 1999). However, this method of stand establishment is typically more expensive due to much higher labor costs.

Most onion varieties planted are long-day varieties, adapted for northern latitudes. These onions begin to bulb when day length reaches 14-16 hours. Harvest

typically begins in mid July and continues through late September. Onions are undercut and bulbs are left to cure in the field for days or weeks before they are harvested, graded and packed. Most commercially produced onions are sold at fresh markets locally and along the eastern Seaboard from August to April.

C. Production challenges

Intensive management of onions has led to many biotic challenges including problems with weeds, disease and insect pests. Broadleaf and grass weeds commonly encountered in onions fields include yellow nutsedge (*Cyperus esculentus*), redroot pigweed (*Amaranthus retoroflexus*), prostrate spurge (*Euphorbia humistrata*), common purslane (*Portulaca oleracea*), shepherd's purse (*Capsella bursa-pastoris*), common ragweed (*Ambrosia artemisifolia*) and common lambsquarters (*Chenopodium album*) (Stivers 1999, Larentzaki et al. 2007). Weed competition can have a major effect on crop yield depending on weed density and competitive ability of the crop. Onion has a very low competitive ability partially due to their relatively shallow root system and is thus highly susceptible to weed competition (Van Heemst 1985). Weeds can also interfere with adequate coverage of onion foliage with insecticides and fungicides. In large commercial field operations, common weed management practices include manually removing weeds and spraying herbicides (*Cornell Vegetable Program* 2012). For small-scale farmers, growing onions on plastic mulch is an additional option frequently used for weed control.

Onions are also susceptible to several diseases during the growing season and are further susceptible to rots and molds in storage. These diseases include bacterial soft rot (*Erwinia carotovora*, sub. sp. *Carotovora*), slippery skin (*Pseudomonas gladioli pv.allicola*), sour skin (*Burkholderia cepacia*), center rot (*Pantoea ananatis*), Enterobacter rot (*Enterobacter cloacae*), basal rot (*Fusarium oxysporum* f. sp. *cepae*), botrytis leaf blight (*Botrytis squamosa*), downy mildew (*Peronospora destructor*), purple blotch (*Alternaria porri*), onion smut (*Urocystis colchici*), onion yellow dwarf virus, and iris yellow spot virus (*Cornell Vegetable Program* 2012). Such diseases can kill leaves, reduce bulb size, and reduce yield (Hoffmann et al. 1996). The bacterial diseases can cause further economic damage in storage.

Because onion is such a high-value crop, there is low tolerance for insect damage that reduces bulb size, quality, or both. Onion maggot (*Delia antiqua* M.) and onion thrips (*Thrips tabaci* L.) are the two most economically important insect pests of onions in New York State (Hoffmann et al. 1996). In the case of onion maggot, adult females lay their eggs near the base of the onion and maggots feed on roots and burrow into below ground structures of the plant. Infestations early in the season cause onion seedlings to wilt and die. If plants are not protected, loss due to onion maggot damage can be up to 40 to 65% (Finch 1989, Nault et al. 2011).

II. Onion Thrips, *Thrips tabaci* Lindemann (Thysanoptera: Thripidae)

A. Life History

Thrips tabaci is a polyphagous species with a wide range of host plants (Diaz-Montano et al. 2011), but onion is its preferred host (Doederlein and Sites 1993, Lewis 1997). *T. tabaci* can reproduce sexually and asexually through parthenogenesis with both reproductive modes occurring in New York State (Nault 2006). Thelytokous populations (females produced from unfertilized eggs) are most common, with arrhenotokous (males produced from unfertilized eggs) and deuterotokous populations (males and females produced from unfertilized eggs) occurring sporadically.

Adults vary in color and size depending on temperature during development; generally *T. tabaci* are pale yellow to brown, about 1.0 – 1.3mm in length, with males being smaller than females (Diaz-Montano et al. 2011). Adult females oviposit eggs into leaf tissue (Terry 1997). First and second instars often appear pale yellow in color and resemble adults in shape. Immature thrips grow in size as they feed, with late first instars often appearing very similar to early second instars (Moritz 1997). The prepupal and pupal stages follow, with pupation typically taking place in soil (Lall and Sinch 1968). *T. tabaci* develops quickly, taking two or three weeks to develop from egg to adult (Theunissen and Legutowska 1991, Ananthakrishnan 1993, Kirk 1997a, Mound 2005).

Short generation times and high fecundity further contribute to the pest status of *T. tabaci*. At an optimal temperature of 23˚C, *T. tabaci* can complete its life cycle in 18 days (Fournier et al. 1995, Murai 2000). Murai (2000) also found that net reproductive rate for *T. tabaci* was greatest at 23˚C. With such short development

time and high average temperatures during the growing season, *T. tabaci* can have four to six generations every season in New York (Nault 2006, Waiganjo et al. 2006).

B. Ecology

T. tabaci overwinter as adults and have been found on cull onions, volunteer onions, weedy vegetation, and in soil on the interior and edge of onion fields (Kritzman et al. 2001, Larentzaki et al. 2007, Srinivasan et al. 2012). Furthermore, adult *T. tabaci* in cabbage fields have also been found to overwinter within winter wheat, *Triticum aestivum,* and alfalfa, *Medicago sativa* (North and Shelton 1986, Pozzer et al. 1999). Overwintering populations typically emerge around the time onions are planted and begin reproducing as early as mid-March on volunteer onions and weedy vegetation (Larentzaki et al. 2007, Smith et al. 2011, Hsu et al. 2011). These populations typically colonize the main crop of onions in mid- to late-June. When most onions are harvested in late August and September, *T. tabaci* populations on weedy vegetation begin to increase. While there is weedy vegetation within onion fields, these typically are not exploited by *T. tabaci* and are generally not considered important weed hosts.

C. Damage to Onion Crop

T. tabaci typically feeds and reproduces on onion leaves, thereby causing indirect damage to the crop. There are a few instances where thrips have been known to feed directly on the bulb (Harris et al. 1935, Hsu et al. 2011). *T. tabaci* is thigmotactic, with adults and larvae hiding in leaf folds and between touching

leaves, and prefer to feed on the youngest leaves with their piercing-sucking mouthparts (Theunissen and Legutowska 1991, Kirk 1997a, Mound 2005, Gray et al. 2009). Thrips feeding causes leaf necrosis thereby reducing photosynthetic ability and consequently can cause reductions in bulb size and weight (Fournier et al. 1995, Shelton et al. 2006, Rueda et al. 2007). Severe infestations can reduce bulb size by up to 60% (Kirk 1997b, Waiganjo et al. 2006); however, the threshold of economic injury is difficult to assess because damage is typically not directly done to the onion bulb.

Additional damage to onions can be caused by pathogenic infection. *T. tabaci* and the tobacco thrips, *Frankliniella fusca*, are the only known vectors of *Iris yellow spot virus* (IYSV) (Kritzman et al. 2001, Shelton et al. 2003, 2006, Srinivasan et al. 2012), although only *T. tabaci* has been shown to transmit IYSV to onion. IYSV is a Tospovirus that causes dry lesions on onion leaves and can cause reductions in photosynthesis and as well as kill plants before they produce bulbs (Pozzer et al. 1999, Reiners and Petzoldt 2012, Nault and Shelton 2012). In New York, IYSV was first found near Elba in 2006 (Nault and Hessney 2008, Hoepting et al. 2012) and has since been found in onion producing areas throughout the state at varying levels (Nault and Shelton 2010, Hsu et al. 2011). Thus, management of *T. tabaci* is necessary for both the damage done by the pest as well as to manage spread of infectious diseases in onion.

III. Integrated Pest Management of Onion Thrips in New York State

Integrated pest management relies on multiple tactics including chemical, cultural and biological control to manage pest populations below the economic injury level. IPM takes into consideration complimentary strategies to manage pests based on ecological, economic, and social considerations (Nault et al. 2006, Gray et al. 2009). Recent investigations into various types of management strategies for onion thrips, especially in NY, are summarized below.

A. Chemical Control

Onion thrips is the only insect pest in New York onion fields targeted with foliar insecticide applications. In the 1990s and early 2000s, conventional practices to control *T. tabaci* relied on weekly to twice-weekly insecticide sprays with up to twelve applications per season (Pimentel et al. 1992, Shelton et al. 2006, Rueda et al. 2007). Insecticide efficacy may be limited in some cases by inadequate spray coverage as thrips often feed on the inner leaves where they can be protected from spray droplets (Kirk 1997b, Radcliffe et al. 2009). Additionally, their short generation time has contributed to the development of resistance to many insecticides (Shelton et al. 2003, 2006). Rotating between classes of insecticides may help minimize or delay the development of resistance (Diaz-Montano et al. 2010, Reiners and Petzoldt 2012, Nault and Shelton 2012). Recently, there have been reports of better control of *T. tabaci* infestations with novel, selective insecticides (Smith 2006, Nault and Hessney 2008). Moreover, action thresholds have been developed for the selective insecticides, which have been shown to

reduce the number of applications needed to protect the crop during the season (Shelton et al. 1998, Voorrips et al. 2008, Nault and Shelton 2010). Despite these advancements, reliance on insecticides continues and the possibility of resistance development still remains. Population dynamics and reproductive modes of *T. tabaci* contribute to the concern of resistance development. With many of New York *T. tabaci* populations being thelytokous (Nault et al. 2006, Fathi et al. 2011), resistant females should quickly contribute to resistant populations. In addition to the evolution of resistance, frequent applications of pesticides can have potentially damaging effects on non-target organisms, the environment and human health (Pimentel et al. 1992, Arif et al. 2004).

B. Cultural, Mechanical and Physical Control

Non-chemical controls for pest management include cultural techniques that reduce pest establishment, as well as mechanical and physical controls that kill a pest directly or make the habitat unsuitable (Mirnezhad et al. 2009, Radcliffe et al. 2009). Alternative strategies for *T. tabaci* management may help mitigate previously mentioned detrimental effects. For example, straw mulch applications reduced *T. tabaci* populations when compared to bare soil in research trials without compromising yield (Larentzaki et al. 2008, Schwartz et al. 2009, Boateng et al. 2011). Applications of kaolin clay reduced thrips oviposition, hatching and feeding, as well as overall thrips densities (Hamilton et al. 1999, Larentzaki et al. 2008, Diaz-Montano et al. 2010). Adoption of these alternative management strategies has been slow due to practical limitations, growing conditions and further economic

costs. As a result, more research is necessary to identify an alternative strategy that is practical, economical, and appropriate for New York State.

C. Host Plant Resistance

While chemical control is the main tactic for managing *T. tabaci* in New York, adequate spray coverage and resistance development are two important considerations that hinder effectiveness of insecticides (Eilenberg et al. 2001, Diaz-Montano et al. 2010). Host plant resistance may be a significant element in managing *T. tabaci* in onion. There are three general categories of host plant resistance including antixenosis, antibiosis, and tolerance. Plants exhibiting antixenosis are poor hosts for pests, often having stimuli that are unattractive or non preferential to the pest, and affect pest behavior. Antibiosis is a kind of resistance in which the host plant negatively affects the biology of the insect and can result in injury, reduced longevity or fecundity, or death of the insect. Host plants that are tolerant are able to withstand injury or recover from pest injury (Eilenberg et al. 2001, Smith 2006).

Host plant characteristics for resistance to thrips have been explored in other crop systems including cabbage (Shelton et al. 1998, Deligeorgidis et al. 2005, Voorrips et al. 2008), canola (Gabarra et al. 1995, Wimmer et al. 2008, Fathi et al. 2011), cotton (Arif et al. 2004, Jung 2004), and tomato (Atakan et al. 1996, Mirnezhad et al. 2009). Classical breeding efforts in the US are underway to develop thrips-resistant onion cultivars (Bosco and Tavella 2010, Boateng et al. 2011). Resistance to *T. tabaci* has been evaluated for dozens of existing onion cultivars and

some in development (Hamilton et al. 1999, Diaz-Montano et al. 2010, Mautino et al. 2011). Unfortunately, these promising cultivars may not be suitable for production in New York. Further exploration of regionally appropriate thrips-resistant onion cultivars is necessary for *T. tabaci* management.

D. Biological Control

Biological control, or biocontrol, is defined as "the use of living organisms to suppress population density or impact of a specific pest organism, making it less abundant or less damaging than it would otherwise be" (Eilenberg et al. 2001, Musser and Shelton 2003, Mahmoud and Osman 2007). Classical biocontrol typically refers to the introduction of exotic biological control agents for long-term pest management, while inoculation and inundation biological control refer to episodic introductions of biological control agents for immediate pest control, such as in greenhouses (Ananthakrishnan 1993, Eilenberg et al. 2001). The ladybird beetle *Coccinella septempunctata* was an effective predator of *T. tabaci* on greenhouse tomatoes (Castañé et al. 2000, Deligeorgidis et al. 2005, Mound 2005). Inoculative biocontrol to manage the western flower thrips, *Frankliniella occidentalis*, as well as *T. tabaci* has also shown some promise in greenhouse production of cucumber (Gabarra et al. 1995, Sabelis and Van Rijn 1997, Kirk 1997b, Wimmer et al. 2008). Other biological control agents such as pathogenic fungi and nematodes have been shown to reduce the number of thrips per plant and frequency of infestation when used in combination to treat *T. tabaci* on onion in Germany (Ananthakrishnan 1993, Loomans and van Lenteren 1995, Jung 2004).

However, the potential for field scale inoculation of predators for *T. tabaci* management on onion is largely unknown.

At the field scale, the distribution of naturally occurring predators of *T. tabaci* on different varieties of cotton has been evaluated in the coastal plains of Israel (Atakan et al. 1996, Workman and Martin 2002). Though dependent on cotton variety, positive correlations between predator location and *T. tabaci* indicate conservation biological control, or the enhancement of particular natural enemies already present, may be the most easily implemented form of biological control for thrips management. In leek systems in Italy, the mean number of *T. tabaci* per plant was lower in biological control treatments with naturally occurring predators when compared to chemical control treatments (Bosco and Tavella 2010, Eyre et al. 2011).

However, continued insecticide use for thrips control in onion will likely be a significant component of thrips management strategies. If chemicals are used judiciously and applied appropriately, natural enemies may be conserved (Eyre et al. 2011, Mautino et al. 2011). Furthermore, selective insecticides may be compatible with biological control agents such as natural enemies and parasitoids, as has been shown in onion as well as other cropping systems (Musser and Shelton 2003, Mahmoud and Osman 2007). Key predators of thrips in nature include parasitic nematodes, mites and predatory species in Hemiptera, Coleoptera, and Neuroptera (Ananthakrishnan 1993). Anthocorid bugs have been recognized as a major natural enemy of thrips (Castañé et al. 2000, Mound 2005). Predators of *T. tabaci* include anthocorid bugs (Anthocoridae), lacewing larvae (Neuroptera),

ladybird beetles (Coccinellidae), hoverfly larvae (Syrphidae), and other predatory thrips (Aeolothripidae) (Sabelis and Van Rijn 1997, Kirk 1997b).

Endoparasitic wasps in the families Eulophidae, Chalcidae, Trichogrammatidae and Mymaridae are the main parasitoids of thrips (Ananthakrishnan 1993, Loomans and van Lenteren 1995). Conservation of these beneficial organisms may help control *T. tabaci* populations if integrated with the use of selective insecticides. Populations of natural enemies were found to vary with standard and selective insecticide treatments for *T. tabaci* in New Zealand (Workman and Martin 2002). These included *Ceranisus menes* parasitoid wasps, syrphid larvae, *Buchananiella whitei* (Hemiptera: Anthocoridae) and the predatory thrips *Aeolothrips fasciatum*. Furthermore, the highest numbers of predators were found 45m away from field margins toward the interior of the field, such as ladybird beetles, hoverflies, lacewings and parasitic wasps (Ichneumonidae) in organic leek fields in England (Eyre et al. 2011). These levels of predators were associated with the lowest levels of *T. tabaci* damage, indicating potential benefits of management practices that are supportive of natural enemy populations (Eyre et al. 2010).

IV. Research Objectives

The goal of this research project was to identify key predators of *T. tabaci* in New York onion systems. The primary objectives were to (1) identify the predators of *T. tabaci* in onion fields in New York, (2) compare the diversity and abundance of these predators onions grown in both large-scale and small-scale production

systems, and (3) describe the temporal and spatial patterns of the key natural enemies as well as *T. tabaci* in these onion fields.

This research was completed to give insight into the role that insect predators may have in thrips pest management and its potential for integration into an IPM program for onion thrips. This information can be applied to determine whether or not selective insecticides or alternative management practices are likely to conserve beneficial insects to make a practical impact on reducing *T. tabaci* populations.

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Chapter 2

PREDATOR ASSEMBLAGES AND THEIR IMPACT OF *THRIPS TABACI* LINDEMAN POPULATIONS IN MONOCULTURE AND POLYCULTURE ONION SYSTEMS

Abstract

Pest management can be enhanced by vegetational diversity in agroecosystems through the enemies hypothesis or the resource concentration hypothesis. Onion thrips, *Thrips tabaci* Lindeman, is the primary foliar-feeding pest of onion, which may be grown in either large monoculture fields typically surrounded by other onion fields, or in small polyculture fields surrounded by fields of multiple vegetable crops. In 2011 and 2012, populations of *T. tabaci* and their predators were assessed in onions grown in both kinds of systems during the season by visual counts on plants and via yellow sticky cards. The species richness of predators in monoculture and polyculture systems was identical, but predator abundance was greater in polyculture systems. Populations of predators and *T. tabaci* were relatively synchronous throughout each season when thrips were present on onion plants. Where insecticides were not used, *T. tabaci* populations were lower in polyculture systems than in monoculture systems. These results suggest that predators may be reducing *T. tabaci* populations in onions in polyculture systems more so than in monoculture systems, at least for those grown without insecticides. Predator populations may have benefited from the vegetational diversity in the polyculture systems, which is consistent with

exploration of the enemies hypothesis, suggesting that further habitat diversification strategies in onion agroecosystems could foster higher predator populations and contribute to management strategies of *T. tabaci* pest populations.

1. Introduction

In agricultural ecosystems, biodiversity can provide multifunctional benefits at many trophic levels (Gurr et al., 2003). Pest management can be enhanced by top-down or bottom-up mechanisms, elucidated by the enemies hypothesis or the resource concentration hypothesis, respectively (Root, 1973). The enemies hypothesis states that natural enemies are more abundant in polyculture systems and are thus able to suppress herbivore pest populations to a larger extent compared with monoculture systems. In contrast, the resource concentration hypothesis states that herbivore pests are more likely to persist in higher populations when the host resource is concentrated, as in monoculture systems. Thus vegetational diversity may enhance pest management through these two complementary mechanisms. Populations of natural enemies have been shown to benefit from diversification strategies, but this has not always led to increased biological control of the pest (Andow, 1991; Landis et al., 2000). The degree to which systems are diversified may impact natural enemy populations and the potential for biological control.

Onions are grown in both monoculture and polyculture production systems. In New York State (U.S.A.), onions grown in monoculture are often partitioned in 2 to 4 ha fields, but these fields may be contiguous and span hundreds of hectares. In

contrast, onions grown in polyculture are planted in fields ranging from <0.04 to 0.8 ha on small-diversified farms with multiple crops growing in adjacent fields. Polyculture systems may be characterized by the kinds of diversification strategies in practice such as altering the structural diversity of the crop, growing multiple varieties of one crop, allowing weedy vegetation to persist, growing multiple crops within a field, leaving fallow fields adjacent to crop fields, integrating agroforestry or livestock, or conserving woodlands or natural habitats surrounding the farm (Gurr et al., 2003). Habitat diversity is typically greater in onion ecosystems grown in polyculture than in monoculture.

Onion thrips (*Thrips tabaci* Lindeman), is one of the most economically important insect pests of onions (*Allium cepa* L.) worldwide (Diaz-Montano et al., 2011). In New York, *T. tabaci* is the most damaging insect pest of onion (Hoffmann et al., 1996) and the only significant foliar insect pest (Gangloff-Kaufmann, 1999). *T. tabaci* indirectly damages the crop by feeding and reproducing on onion leaves, wtih four to six generations every season (Nault, 2006). Adults and larvae hide in leaf folds and between touching leaves, preferring to feed on the youngest leaves with their piercing-sucking mouthparts (Kirk, 1997a; Mound, 2005, Theunissen and Legutowska, 1991). Thrips feeding causes leaf necrosis, which reduces photosynthetic ability and consequently bulb size and weight (Fournier et al., 1995). Severe infestations can reduce bulb size by up to 60% (Waiganjo et al., 2006); however, the threshold of economic injury is difficult to assess because damage is typically not directly done to the onion bulb (Nault and Shelton, 2010).

Conventional control of *T. tabaci* has relied on regular applications of insecticides (Diaz-Montano et al., 2011; Nault and Shelton, 2010; Shelton et al., 2006), but efficacy may be limited due to inadequate spray coverage as thrips are thigmotactic (Kirk, 1997a). Recently, novel selective insecticides have been shown to reduce the number of applications needed to protect the crop during the season (Nault and Shelton, 2010). Anecdotally, there have been reports of more predatory insects observed in onion fields since these management changes have been adopted. However, the species richness and abundance of predators in onion ecosystems in New York are not known, nor is the impact that predators may have on *T. tabaci* populations.

The overall goal of this research was to assess the naturally occurring populations of predators in onions grown in monoculture and polyculture systems. The primary objectives of this research were to (1) identify the potential predators of *T. tabaci* and their relative abundance in the two types of onion production systems in New York, (2) describe the temporal patterns of the predator and *T. tabaci* populations in these onion fields, and (3) explore to what extent predator abundance can be predicted by *T. tabaci* abundance within the two onion production systems. We hypothesized that (1) predator richness and abundance in onion fields would increase with increased vegetational diversity. Within both systems, we predicted (2) predator population dynamics would be synchronous with *T. tabaci* populations, and (3) predator abundance would increase in response to greater *T. tabaci* abundance. Overall, we expected that populations of *T. tabaci* in

onions grown in a polyculture system would be lower than in a monoculture system because predator abundance would be greater in a polyculture system.

2. Materials and methods

2.1 Site description and experimental design

Research was conducted in major onion-producing regions in central and western New York in 2011 and 2012. Onion production systems were classified as either a monoculture or polyculture (SYSTEM). Monoculture systems included onion fields that were part of a contiguous series of onion fields ranging from 40 to over 1,000 ha and surrounded by woods, whereas polyculture systems included a single onion field < 2 ha surrounded by other vegetable crops such as cabbage, lettuce, potato, squash and sweet corn. Weeds were uncommon within onion fields in monoculture systems and much more common in fields in polyculture systems. Polyculture systems met one or more diversification strategies designed to enhance biological control and benefit pest management (Gurr et al., 2003). Monoculture and polyculture systems were separated by a minimum of 6 km and onion fields sampled within a system were separated from each other by at least 0.1 km.

Predator richness and abundance as well as *T. tabaci* abundance were assessed in onion fields grown following commercial production practices and in small plots not treated with insecticides. Grower-managed onion fields were planted with a variety of cultivars and employed various *T. tabaci* management practices (i.e., insecticide spray frequency, products used, and production methods). Because these management practices could differentially affect predator richness

and abundance and *T. tabaci* abundance, insect populations were also monitored in small insecticide-free plots, within which the same cultivar of onion was grown.

Grower-managed onion fields. In 2011, four monoculture and four polyculture sites were sampled for a total of eight sites. In 2012, six monoculture and six polyculture sites were sampled for a total of twelve sites. Onion fields used in the study were managed according to recommended guidelines for insect management in New York (Reiners and Petzoldt, 2012). In general, highly effective insecticides (e.g., spirotetramat [Movento], abamectin [Agri-Mek] and spinetoram [Radiant SC]) were used nearly every week in monoculture systems, while less effective products (e.g., Entrust, various oils) were used less frequently in polyculture systems. No modifications were made to planting, management, or harvest practices in these onion fields; thus, we considered these to be "grower-managed fields".

Insecticide-free onion plots. Small plots of onions, var. 'Red Bull' (25m of row), were transplanted within grower-managed fields at each site along or near the edge of the field shortly after the grower-managed fields were planted. In 2011, onions were transplanted from 30 April through 6 June at all sites. In 2012, onions were transplanted between 9 May and 30 May at all sites. Transplanted onions in these insecticide-free plots were protected from onion maggot, *Delia antiqua* (Meigen), by dipping the lower half of each plant in a solution of spinetoram (Radiant SC, Dow AgroSciences, Indianapolis, IN) and water at a rate of 60 ml of product per 3.8L of water. Based on previous research, this practice only protects the onion crop from maggots early in the season and does not impact the timing of

T. tabaci colonization (BAN, unpublished data), which does not begin until June (Smith et al., 2011). *T. tabaci* was the only foliar-feeding insect that attacked onions in this two-year study and voucher specimens have been deposited in the Cornell University Insect Collection, Ithaca, NY. No foliar insecticide applications were made to the onion plots throughout the season; thus plots were considered "insecticide-free".

2.2 Sampling

To assess predator richness and abundance as well as *T. tabaci* abundance, grower-managed fields and insecticide-free plots were sampled immediately before *T. tabaci* colonization and continued until onion harvest. Sampling in 2011 began on 31 May and continued weekly until 1 September. In 2012, sampling occurred weekly from 30 May to 20 August. Two methods were used to sample insects: visual on-plant counts and yellow sticky cards.

In grower-managed fields, 90 and 30 onion plants were randomly selected in 2011 and in 2012, respectively, and all predators and *T. tabaci* larvae were visually counted and recorded. Similarly, in insecticide-free plots, 30 onion plants were randomly selected and numbers of *T. tabaci* larvae and all predators were visually counted and recorded (on-plant counts).

Predators may have been active at times when plants were not sampled visually. Thus, to increase the likelihood of a more accurate census of the predators in the system, yellow sticky cards were used (7cm x 12cm) (Olson Products, Medina, OH) to sample predators as well. In 2011 and 2012, two cards and one card,

respectively, were placed in the middle of each insecticide-free plot. Sticky cards were fastened to 91cm tall wooden stakes using plastic spring loaded clamps (Woodworker's Supply, Casper, WY). Cards were positioned 10-30cm above the ground within the onion plant canopy and replaced weekly. Predators from yellow sticky cards were identified and counted at a later date. *T. tabaci* captured on yellow sticky cards were not recorded because on-plant *T. tabaci* count data were likely a more accurate measure of estimating abundance because thrips larvae were not captured on sticky cards. Yellow sticky cards were not used to monitor predator populations in grower-managed fields.

2.3 Statistical analyses

Climate differed substantially in 2011 and 2012, so data were analyzed separately by year. In 2011, spring was cool and wet, which delayed planting in all onion growing regions in New York. In contrast, spring in 2012 was extremely mild, which allowed for earlier than normal planting; additionally, the 2012 growing season was attenuated by drought and the crop matured earlier than usual.

To compare *T. tabaci* abundance between monoculture and polyculture systems, mean densities were analyzed using a t-test in JMP Pro 10 (SAS Institute Inc., 2012). Means for grower-managed fields and insecticide-free plots were calculated separately. Means were calculated by averaging *T. tabaci* per plant within each week and site, then averaging across weeks.

To illustrate relative population trends of predators and *T. tabaci* through time in monoculture and polyculture systems, mean predators per plant and mean

T. tabaci per plant were standardized using z-scores $(z = (x - \mu)/\sigma)$ and illustrated on a weekly basis.

A generalized linear model was used to estimate the effects of onion production (SYSTEM), *T. tabaci* abundance (THRIPS) and their interaction on mean predator abundance using the GENMOD procedure in SAS v. 9.3 (SAS Institute Inc, 2011). WEEK was included in the class statement to account for changes in mean insect abundance through time, but was not included in the model statement. Because insect counts were overdispersed, data were modeled using a negative binomial distribution. A repeated statement was also included with SITE as the subject specifying a type-1 autoregressive covariance structure. Separate models were conducted for all predator datasets: on-plant counts in grower-managed fields, on-plant counts in insecticide-free plots, and sticky cards in insecticide-free plots.

Predator abundance in each taxonomic group was very low and precluded robust comparisons. Thus, for all data analyses pertaining to predator counts, total numbers of predators rather than each taxonomic group of predators were analyzed.

3. Results

3.1 Abundance of T. tabaci in onion systems

In grower-managed onion fields, average abundance of *T. tabaci* in monoculture systems was numerically lower than in polyculture systems in 2011 (n=8, *P*=0.191) and 2012 (n=12, *P*=0.106), but these difference were not significant (Table 1). In insecticide-free onion plots, average abundance of *T. tabaci* in

Table 1. Season mean densities of *T. tabaci* per plant (±SEM) in onions grown in grower-managed fields and insecticide-free plots in monoculture and polyculture onion agroecosystems in 2011 and 2012 in New York (2011: n= 4 sites; 2012: n= 6 sites).

		SYSTEM	
		Monoculture	Polyculture
2011	Grower-managed field	5.54 ± 1.55	10.13 ± 2.60
	Insecticide-free plot	11.97 ± 5.04	9.67 ± 2.18
2012	Grower-managed field	3.36 ± 1.08	14.50 ± 5.64
	Insecticide-free plot	21.26 ± 2.72	10.37 ± 5.16

polyculture systems was lower than in monoculture systems in 2011 (n=8, *P*=0.701) and 2012 (n=12, *P*=0.101); however, these difference were not statistically significant.

3.2 Predator richness and abundance on onion plants

In 2011 and 2012, predator species encountered in monoculture and polyculture production systems included *Aeolothrips fasciatus* (L.) (Aeolothripidae), *Aeolothrips albicinctus* Haliday (Aeolothripidae), *Toxomerus marginatus* (Say) (Syrphidae), *Sphaerophoria pyrrhina* Bigot (Syrphidae), *Orius insidiosus* (Say) (Anthocoridae), *Coleomegilla maculata* De Geer (Coccinellidae), *Hippodamia variegata* (Goeze) (Coccinellidae) and lacewing larvae (Chrysopidae). All of these species were observed feeding on *T. tabaci* larvae in the onion fields as well as in caged laboratory experiments. Overall, abundance of all predators from on-plant sampling was low in monoculture and polyculture systems in both 2011 and 2012 (Table 2). Season means of each taxonomic group were typically higher in polyculture systems (Table 2). Similarly, total abundance of all species combined was numerically greater in polyculture systems in both 2011 and 2012 (Table 2).

3.3 Synchrony of predator and thrips seasonal dynamics on onion plants

Populations of predators and *T. tabaci* were generally sychronous in both production systems during the season. In 2011, mean abundance of predators was greatest between week 7 and week 9 (late July) in monoculture (Figure 1A and 1C). This was similar in polyculture systems with the predator abundance peaking at

Table 2. Total mean predators (± SEM) in small plots of onions in monoculture and polyculture fields per season in 2011 and 2012 in New York (2011: n= 4 sites; 2012: n= 6 sites).

		Grower-managed Fields				Insecticide-free Plots			
		Total per Season		Predator mean ± SE per site per week[a]		Total per Season		Predator mean ± SE per site per week[a]	
Year	Family	Mono	Poly	Mono	Poly	Mono	Poly	Mono	Poly
2011									
	Aeolothripidae	3	159	0.63 ± 0.35	31.18 ± 11.66	3	52	0.64 ± 0.64	8.39 ± 2.06
	Syrphidae	11	37	2.29 ± 1.08	7.26 ± 3.11	5	6	1.06 ± 0.55	0.97 ± 0.44
	Chrysopidae	4	5	0.83 ± 0.50	0.98 ± 0.64	0	0	0 ± 0	0 ± 0
	Anthocoridae	0	39	0 ± 0	7.65 ± 2.80	0	11	0 ± 0	1.77 ± 0.54
	Coccinellidae	1	10	0.21 ± 0.21	1.96 ± 0.93	14	2	2.98 ± 1.09	0.32 ± 0.23
	Total	19	250	3.96 ± 1.36	49.02 ± 17.38	22	71	4.68 ± 1.39	11.45 ± 2.40
2012									
	Aeolothripidae	5	84	0.79 ± 0.34	12.73 ± 3.95	40	118	6.45 ± 1.72	17.88 ± 5.14
	Syrphidae	11	34	1.75 ± 0.89	5.15 ± 2.17	2	21	0.32 ± 0.23	3.18 ± 1.37
	Chrysopidae	2	11	0.32 ± 0.22	1.67 ± 0.63	7	6	1.13 ± 0.52	0.91 ± 0.56
	Anthocoridae	1	5	0.16 ± 0.16	0.76± 0.50	3	1	0.48 ± 0.36	0.15 ± 0.15
	Coccinellidae	1	14	01.6 ± 0.16	2.12 ± 0.76	7	7	1.13 ± 0.47	1.06 ± 0.49
	Total	20	148	3.17 ± 0.96	22.42 ± 5.79	59	150	9.52 ± 2.09	23.18 ± 5.80

[a] multiplied by scale factor of 10

[a] multiplied by scale factor of 10

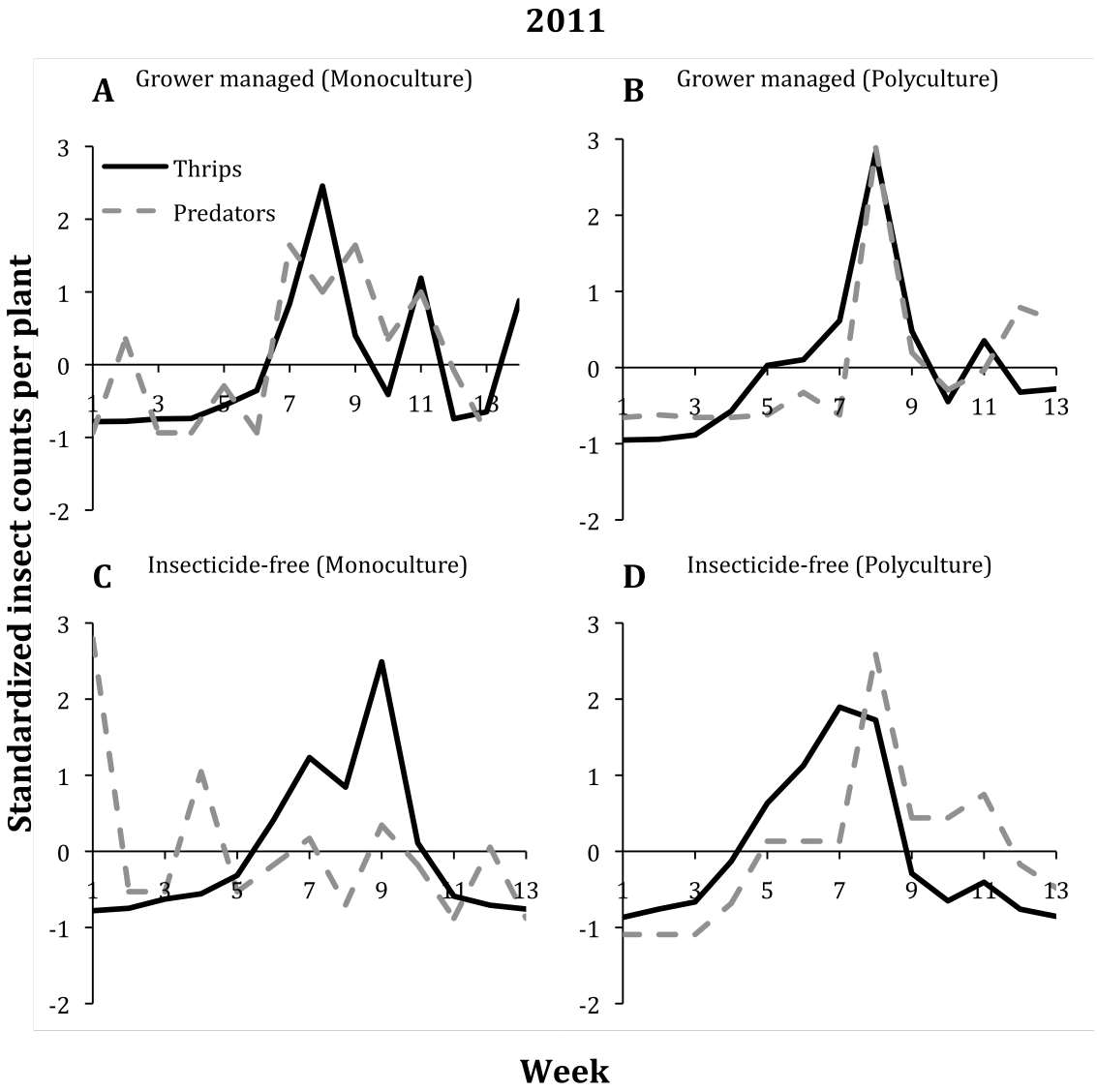


Figure 1. Relationship between standardized average number of predators per plant and standardized average number of thrips per plant in 2011 in grower managed fields through time in monocultures (n=4)(A) and polycultures (n=4)(B) and insecticide-free onion plantings in monocultures (n=4)(C) and polycultures (n=4)(D).

week 8 (Figure 1B and 1D). In 2012, both predators and *T. tabaci* were highest between week 7 and week 8 (late July) (Figure 2). In all cases, predator populations tended to mirror *T. tabaci* populations during the season, with the exception of predators early in the season in both 2011 monocultures. In these cases, there were high numbers of *C. maculata* despite the absence of *T. tabaci* on onions.

3.4 Comparison of season total predator densities between onion production systems

The results of the generalized linear model are presented in Table 3 for all three predator data sets (on-plant counts in grower-managed fields, on-plant counts in insecticide-free plots, and sticky cards in insecticide-free plots). Significant results from the model are also presented as figures to illustrate trends (Figures 3-7). SYSTEM was consistently a significant factor in explaining the variance in predator abundance, except for on-plant counts in insecticide-free plots in 2011. Predator abundance was consistently greater in polyculture fields compared with monoculture fields. THRIPS was significant or approached significance in all data sets (Table 3). In contrast, the interaction term THRIPS*SYSTEM was significant only for on-plant counts in insecticide-free plots in 2011 (Table 3). Significant results for each predator data set are discussed in the sub-sections below.

3.4.1 On-plant counts of predators in grower-managed onion fields

In grower-managed fields, predator abundance in polyculture fields was significantly greater than those in monoculture fields in both 2011 (Figure 3A) (P=0.003) and 2012 (Figure 3B) (P<0.001). In grower-managed onion fields,

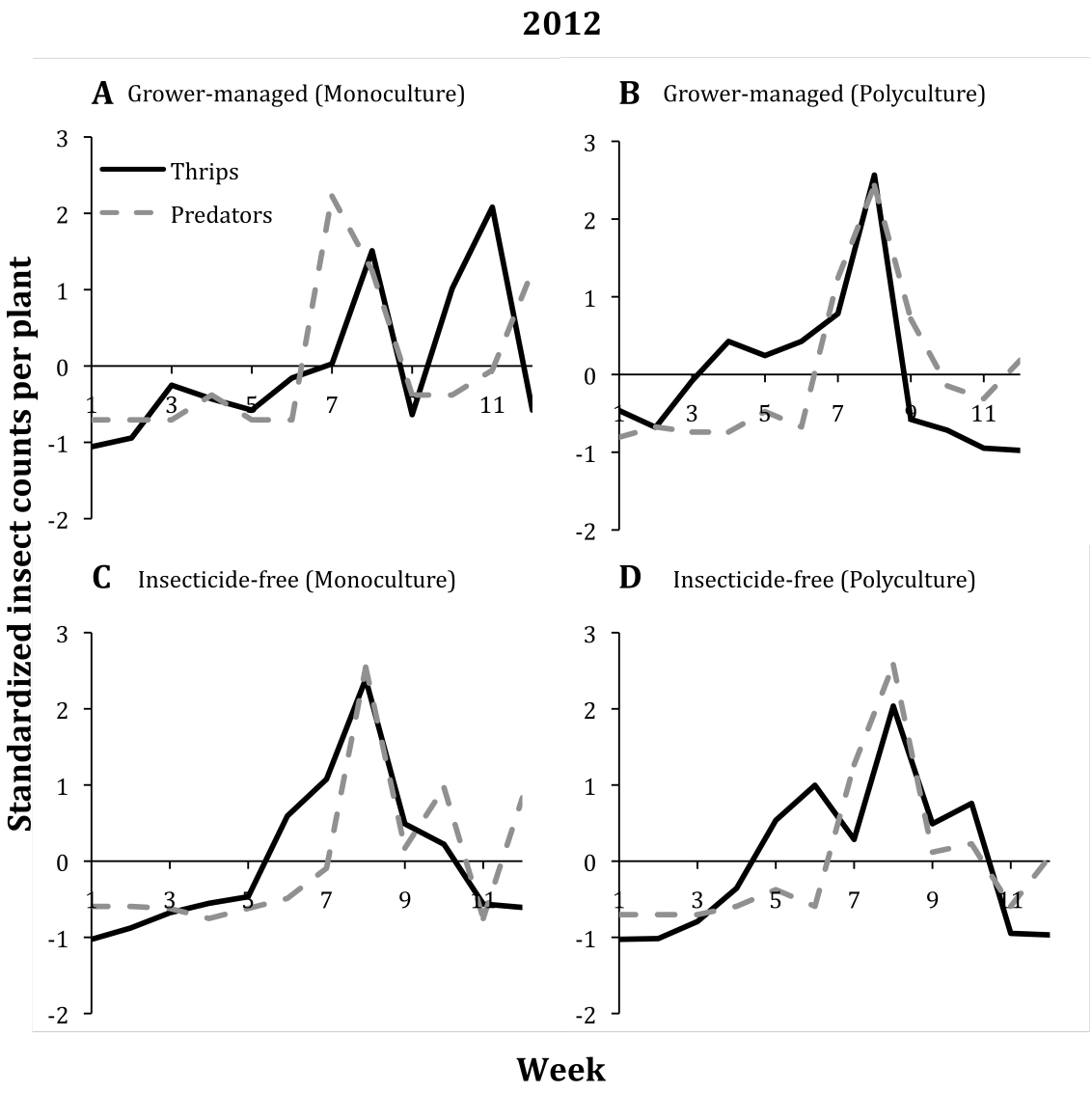


Figure 2. Relationship between standardized average number of predators per plant and standardized average number of thrips per plant in 2012 in grower-managed fields through time in monocultures (n=6)(A) and polycultures (n=6)(B) and insecticide-free onion plantings in monocultures (n=6)(C) and polycultures (n=6)(D).

Table 3. Statistics from the generalized linear model used to analyze predator counts per week in insecticide-free plots of onion and in grower-managed onion fields in monoculture and polyculture fields (SYSTEM) in 2011 and 2012 in New York.

	Grower-managed Plots				Insecticide-free Plots							
	On Plant Count				On Plant Counts				Sticky Cards			
	2011		2012		2011		2012		2011		2012	
Effect	Est.	Pr > |Z|	Est.	Pr > |Z|	Est.	Pr > |Z|	Est.	Pr > |Z|	Est.	Pr > |Z|	Est.	Pr > |Z|
SYSTEM	1.863	**0.003**	1.943	**<0.001**	-0.559	0.371	1.241	**0.002**	0.512	**0.042**	0.539	**0.024**
THRIPS	0.027	**0.015**	0.066	0.093	0.010	**<0.001**	0.024	**<0.001**	0.003	0.070	0.007	0.182
THRIPS * SYSTEM	0.021	0.238	-0.049	0.217	0.034	**<0.001**	0.008	0.390	-0.002	0.774	-0.006	0.345

predator abundance was significantly positively correlated with *T. tabaci* abundance (Figure 4) (*P*=0.015).

3.4.2 On-plant counts of predators in insecticide-free onion plots

The mean number of predators in polyculture systems was higher than in monoculture systems in both years (Table 2), but the differences were only significant in 2012 (Figure 5) (*P*=0.002). In 2011, predator abundance was significantly positively correlated with THRIPS and the interaction term THRIPS*SYSTEM also was significant (Figure 6) (P<0.001). The relationship between predator abundance and *T. tabaci* abundance was positively correlated in both monoculture (y=0.10x-0.30, R^2=0.90) and polyculture systems (y=0.05x+0.38, R^2=0.07), but the relationship was much stronger and greater in monoculture systems. In 2012, there was a significant positive relationship between predators abundance and *T. tabaci* abundance (*P*<0.001) (Table 2).

3.4.3 Sticky cards in insecticide-free onion plots

SYSTEM was significant in both 2011 (Figure 7A) (*P*=0.042) and 2012 (Figure 7B) (*P*=0.024). Mean predator abundance per yellow sticky card in polyculture systems was significantly higher than those in monoculture systems.

4. Discussion

Predator species richness was similar in onion fields grown in monoculture and polyculture, but abundance of predators was consistently higher in onions

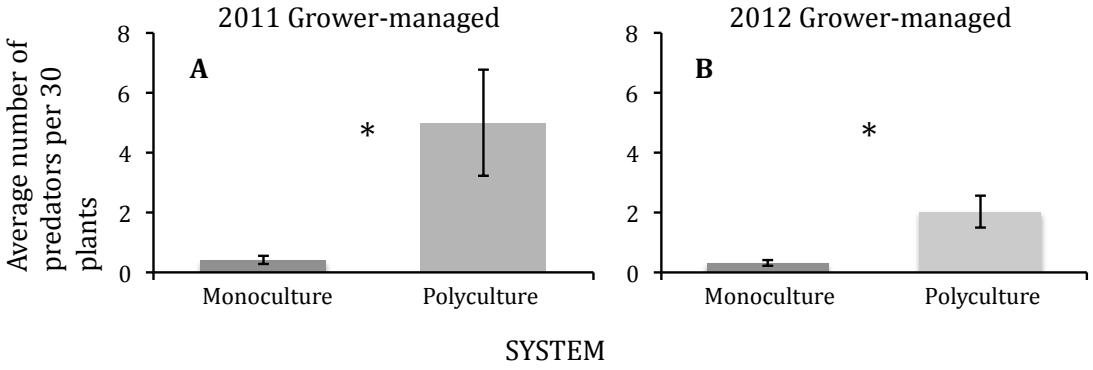
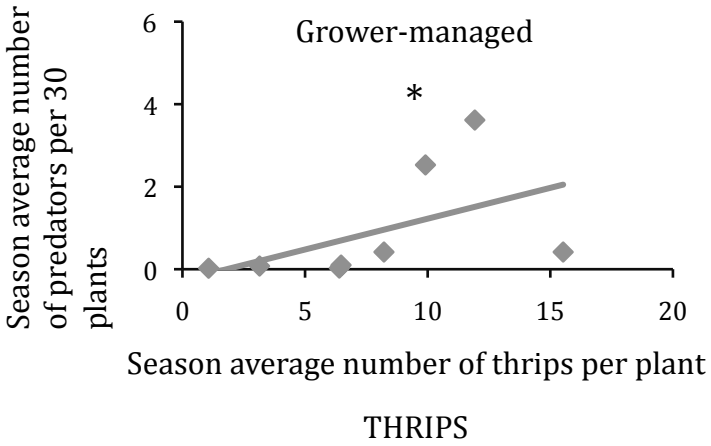


Figure 3. Season average number of predators (± SEM) located in grower-managed onions situated within a monoculture or in a polyculture system that included onions (A) in 2011 and (B) in 2012. The asterisk (*) indicates that the means differ significantly at $P<0.05$ (PROC GENMOD; n=4 in 2011, n= 6 in 2012).



THRIPS

Figure 4. Relationship between season average number of natural enemies and season average number of thrips in all (A) grower managed onions in 2011 (y= 0.15x-0.27, R^2=0.25) and in (B) insecticide-free onion plantings in 2012 (y= $0.01x^3$ – $0.03x^2$ +0.27x + 1.98, R^2=0.46). The asterisk (*) indicates that the means differ significantly at $P<0.05$ (PROC GENMOD; n= 12).

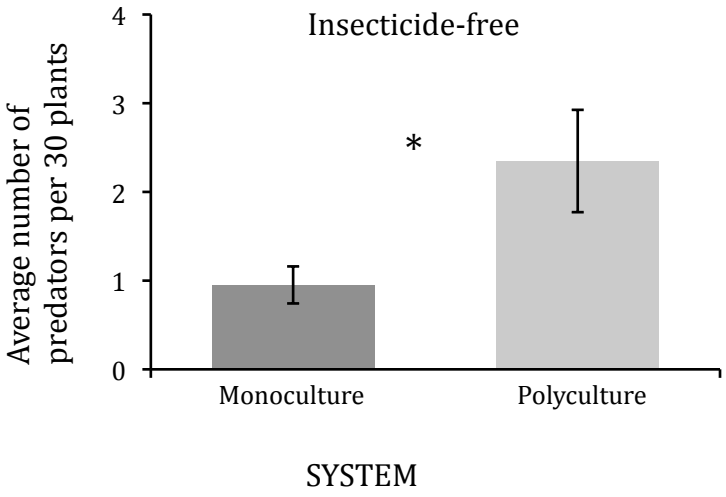
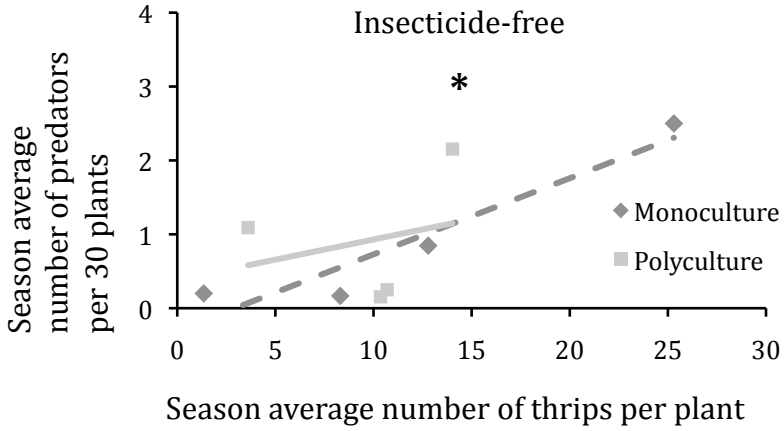


Figure 5. Season average number of predators (± SEM) located in a small planting of insecticide-free onions situated within either a monoculture of onions or a polyculture system that included onions in 2012. The asterisk (*) indicates that the means differ significantly at $P<0.05$ (PROC GENMOD; n= 6).



THRIPS * SYSTEM

Figure 6. Relationships between season average number of predators and season average number of thrips in insecticide-free onion plantings situated within either a monoculture of onions (y=0.10x-0.30, R^2=0.90) or a polyculture system that included onions in 2011 (y=0.05x+0.38, R^2=0.07). The asterisk (*) indicates that the means differ significantly at P<0.05 (PROC GENMOD, n= 4).

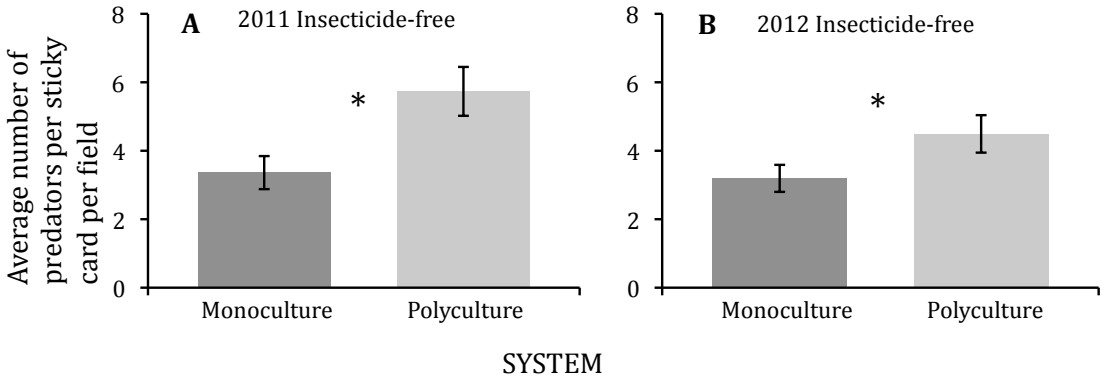


Figure 7. Season average number of predators (± SEM) captured on yellow sticky cards located in insecticide-free onion plantings situated within either a monoculture of onions or a polyculture system that included onions (A) in 2011 and (B) in 2012. The asterisk (*) indicates that the means differ significantly at $P<0.05$ (PROC GENMOD; n=4 in 2011 and n=6 in 2012).

grown in polyculture systems than in monoculture systems. Populations of predators were consistently synchronous with *T. tabaci* populations at times when *T. tabaci* were present on onion plants. *T. tabaci* abundance in polyculture systems was numerically lower than in monoculture systems (in insecticide-free plots) in both years. In grower-managed onion fields where insecticides were used, *T. tabaci* abundance in monoculture systems was lower than polyculture systems; this difference was attributed to the use of highly effective insecticides on a weekly basis in monoculture systems (see Materials and Methods). Our results suggest that predators may be responsible for reducing *T. tabaci* populations in onions grown in polyculture compared with monoculture, at least in situations where predator and thrips populations were not disturbed with insecticides.

To gain more insight into how insecticide use regimens and predators may have impacted thrips populations, a post-hoc test was conducted to evaluate differences in thrips abundance between grower-managed onion fields and insecticide-free onion plots within a monoculture system versus a polyculture system. Differences between mean thrips abundance per site in insecticide-free onion plots and grower-managed onion fields within each system (from Table 1) were then compared between systems using a *t*-test. The difference in thrips abundance between grower-managed fields and insecticide-free plots in monoculture systems was significantly greater than this difference in polyculture systems in 2012 (n=12, P=0.024), but only numerically greater in 2011 (n=8, P=0.295) (Fig. 8). There are two complementary explanations for why the mean difference in *T. tabaci* abundance between grower-managed and insecticide-free

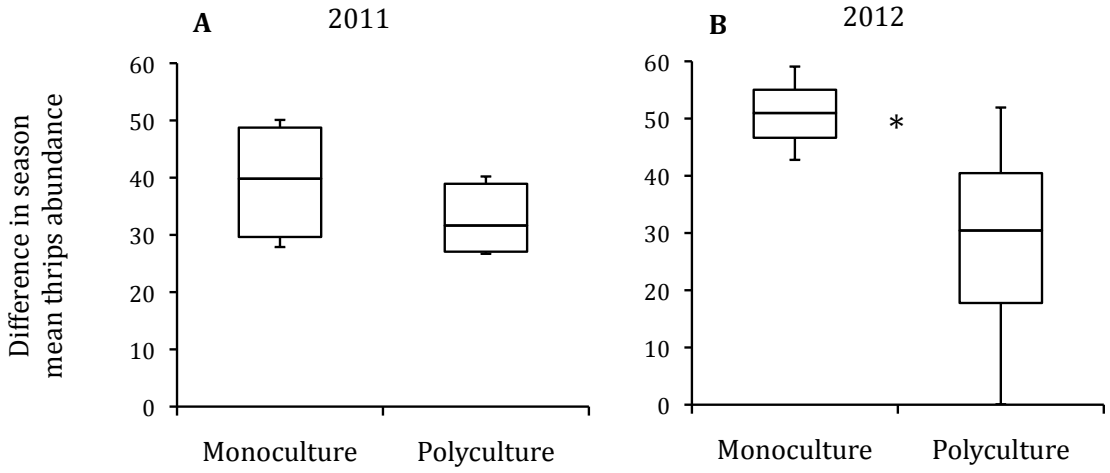


Figure 8. Box plots showing differences in mean season *T. tabaci* abundance between insecticide-free plots and grower-managed fields in monoculture and polyculture systems in 2011 and 2012. A constant of 30 was added to each mean thrips density to improve this illustration. The asterisk (*) indicates that the difference in season means differ significantly at $P<0.05$ (*t*-test, SAS Institute; n=4 in 2011 and n=6 in 2012).

onions in monoculture systems was larger than in polyculture systems. First, the insecticide regimens used in monoculture systems were likely much more effective than those in polyculture systems; this was reflected in the much lower abundance of *T. tabaci* in monoculture systems (Table 1). Second, in insecticide-free plots, *T. tabaci* abundance in polyculture systems was lower than in monoculture systems (Table 1) and there were consistently more predators in the polyculture systems than in monoculture systems (Figs. 5 and 7). Taken together, these results suggest that predators had a greater impact in reducing *T. tabaci* abundance in polyculture systems than in monoculture systems.

The predator complex in both monoculture and polyculture onion production systems in New York included four families and seven genera. The most commonly encountered predator on plants was adult *Aeolothrips fasciatus* (Table 2). Adult *Orius insidiosus* and larval Syrphidae were also frequently encountered (Table 2). Results from our study were consistent with those that observed predators of *T. tabaci* in non-onion cropping systems such as anthocorid bugs (Anthocoridae), lacewing larvae (Neuroptera), ladybird beetles (Coccinellidae), hoverfly larvae (Syrphidae), and predatory thrips (Aeolothripidae) (Kirk, 1997b; Sabelis and Van Rijn, 1997). The same predator species were present in both monoculture and polyculture systems. Providing resources to these predator species through vegetational diversification strategies may help conserve these predators and contribute to thrips management strategies.

While only predators of *T. tabaci* were recorded, parasitoids also may benefit from the vegetational diversity found within polyculture systems. *Ceranisus* spp.

(Hymenoptera: Eulophidae) have been reported as successful parasitoids of *T. tabaci* (Loomans, 2003, 2006; Loomans and van Lenteren, 1995; Waterhouse and Norris, 1989). However, few of these parasitoids have been collected in the continental U.S.A. from *T. tabaci* hosts.

Predator abundance was positively correlated with *T. tabaci* abundance. This relationship was significant in grower-managed fields in 2011 (Figure 4A). This relationship was also significant in insecticide-free plots in 2012 as indicated by the positive model estimate for THRIPS (Table 3). Because of the multivariate model used with the negative binomial distribution, we were unable to appropriately illustrate this trend in a univariate relationship. The positive relationship between predators and *T. tabaci* was furthermore significant in both monoculture and polyculture insecticide-free plots in 2011 (Figure 6) indicating an increase in predator abundance in response to increases in *T. tabaci* abundance. We expected lower *T. tabaci* abundance in grower-managed fields compared with insecticide-free plots, especially in monocultures given the frequent use of insecticides. Even at low *T. tabaci* abundance, predator abundance was significantly positive and highly correlated (R^2=0.90).

In monoculture systems in New York, there are few resources available to predators other than *T. tabaci*. While interguild predation may be a possibility, it is unlikely to be the major contributor to predator populations in monoculture systems. Other resources such as alternate prey, pollen, and shade were available to predators in polyculture systems. While *T. tabaci* were likely important prey for

predator populations, it is likely that other resources were also supporting predator populations, especially in polyculture systems (Polis and Strong, 1996).

The relative synchrony of predator and thrips populations indicated that predators were responding quickly to thrips populations or perhaps were already present in both monoculture and polyculture systems. The exception was *C. maculata* populations in monoculture systems in May in 2011 (see discussion below). In our study, time lag was not a barrier to potential biological control mechanisms, unlike other studies where pests and predators colonize the crop at different times (Price, 1976). This is particularly interesting as there were few other resources available to predators in monoculture systems. Typically, habitat diversification schemes are employed to attract and retain predators in agricultural landscapes to improve pest regulation as a reaction to slow predator response (Altieri and Letourneau, 1982; Andow, 1991; Landis et al., 2000; Letourneau et al., 2011; Poveda et al., 2008). Additional benefits of habitat diversification include potentially improved ecological services such as soil fertility, increased crop yield, conservation of pollinating insects, decreased weedy vegetation, and overall agroecosystem stability (Altieri, 1999; Gurr et al., 2003). These latter benefits may be applicable to New York onion agroecosystems and warrant further investigation.

High densities of *C. maculata* larvae and adults in onion fields in monoculture systems in May 2011 occurred when *T. tabaci* populations were low to absent. These results suggest that *C. maculata* populations were feeding on other prey items, pollen, or fungi. Barley (*Hordeum vulgare* L.) is typically co-planted alongside onion in monoculture production systems because barley germinates more quickly

than onion and protects onion seedlings by serving as a mini windbreak, reducing seedling loss due to high winds and preventing soil erosion (Stivers, 1999). In late May, barley may directly or indirectly support *C. maculata* populations, but research is needed to determine specifically how it may be helping control *T. tabaci* early in the season.

Our study addressed some of the shortcomings of other experimental studies involving manipulation of vegetational diversity (Bommarco and Banks, 2003). Because our monoculture and polyculture systems were separated by at least 8 km, it was unlikely that predators moved between them as in a small-scale garden experiment. Similar to findings of the meta-analysis in Bommarco and Banks (2003), greater habitat diversity led to lower populations of herbivore pests in small plots. We found high predator abundance in polyculture systems with diversified vegetation, especially areas with >2 plant species, which was consistent with Bommarco and Banks (2003) as well as other studies (Letourneau et al., 2011).

Minimizing the level of disturbance (e.g., limited insecticide use) in an agricultural system is important to the successful implementation of biological control (Barbosa, 2008; Gurr et al., 2003; Landis et al., 2000). Yet, insecticide use will likely continue to be a significant component of onion thrips management strategies. If chemicals are used judiciously and applied appropriately, predators may be conserved (Mautino et al., 2011; Root, 1973). Furthermore, selective insecticides may be compatible with biological control organisms such as predators and parasitoids. While varying levels of selective insecticide compatibility with predators has been shown in onion and other cropping systems (Andow, 1991;

Biondi et al., 2012; Landis et al., 2000; Kraiss and Cullen, 2008; Mahmoud and Osman, 2007; Musser and Shelton, 2003), the full extent to which selective insecticides affect suites of predators has yet to be determined.

Advancements have been made in managing *T. tabaci* in onion over the last several decades. Previous research has indicated that agricultural systems typically lack appropriate populations of natural enemies, and the native complex is likely insufficient for thrips control in their current state (Larentzaki et al., 2007; Parrella and Lewis, 1997). However, cultural control such as intercropping and other sustainable approaches have shown promise for future *T. tabaci* management strategies. Diversification strategies in onion agroecosystems will likely foster the development of natural enemy populations, which could contribute to future management strategies of *T. tabaci* populations. While we did not examine diversification beyond the immediate agroecosystem, other studies have indicated positive predator population response to heterogeneous landscapes composed of crop and non-crop habitats (Bianchi et al., 2006; Chaplin-Kramer et al., 2011; Diaz-Montano et al., 2011). The effect of increased predator populations on pest populations, and ultimately the effect on crop yield, is worthy of future research and exploration, especially in the landscape context.

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Chapter 3

CONCLUSIONS AND FUTURE DIRECTIONS

This study investigated impacts of vegetational diversity on predators of onion thrips, *Thrips tabaci* Lindeman, in commercial onion crops in New York State. The naturally occurring predator complex was assessed within monoculture and polyculture systems as well as their relative abundance within each system over two growing seasons. Through this assessment, the same predatory species were found in both monoculture and polycultures. These species included *Aeolothrips fasciatus* (L.) (Aeolothripidae), *Aeolothrips albicinctus* Haliday (Aeolothripidae), *Toxomerus marginatus* (Say) (Syrphidae), *Sphaerophoria pyrrhina* Bigot (Syrphidae), *Orius insidiosus* (Say) (Anthocoridae), *Coleomegilla maculata* De Geer (Coccinellidae), *Hippodamia variegata* (Goeze) (Coccinellidae), and lacewing larvae (Chrysopidae). Predator abundance in onion systems was low overall. Combining taxonomic groups for analysis may inhibit our ability to decipher which predators of *T. tabaci* may be the most impactful in the onion agroecosystem. However, observation of the most common predators, *A. fasciatus* and *O. insidiosus*, indicate they are also the most effective predators due to their size and ability to access plant space unavailable to larger predators. Predator abundance was greater in polyculture systems and was positively correlated with thrips abundance, even at low densities. Overall, predator populations were higher in onion systems that had greater vegetational diversity.

Research was conducted in major onion-producing regions in Western and Central New York. Each research site was classified as a monoculture and polyculture production system. A monoculture site included an onion field that was > 2 ha, often part of a contiguous series of onion fields, whereas a polyculture site included a single onion field < 2 ha surrounded by other vegetable crops such as cabbage, lettuce, potato, squash and sweet corn. Polyculture sites met one or more diversification strategies designed to enhance biological control and benefit pest management (Gurr et al. 2003). Unlike other studies, sites were separated by at least 6km to minimize the possibility of migration by predator populations between sites.

Grower-managed onion fields were planted with a variety of cultivars and employed various *T. tabaci* management practices (i.e. spray frequency, products used, and production methods). Because these management practices could differentially affect predator diversity and abundance (as well as thrips abundance), insect populations were also monitored in small insecticide-free plots, within which the same cultivar of onions was grown. On-plant counts of thrips and predators were taken weekly throughout the growing season at each site. Predators were also monitored using yellow sticky cards in all insecticide-free plots. These sampling methods were used to assess predators and thrips populations throughout the study.

Results indicated that predator populations were relatively synchronous with thrips populations throughout the season, indicating that predators were responding relatively quickly to thrips populations or perhaps were already present

in both monoculture and polyculture systems. In this study, a time lag was not a barrier to potential biological control mechanisms, unlike other studies where pests and predators colonize the crop at different times (Price 1976). Predators were consistently more abundant in polyculture systems compared with monoculture systems. Thrips abundance on onion plants was not significantly different between these two systems, suggesting that predators were responding to alternate factors in polyculture systems. However, the difference in thrips abundance between grower-managed fields and insecticide-free plots in monoculture systems was significantly greater than the difference in polyculture systems. This seems to suggest that insecticides are much more effective in monoculture systems compared to polyculture systems. In insecticide-free plots, however, *T. tabaci* abundance was lower in polyculture compared with monoculture. It is likely that predators may have been responding to other resources such as alternate prey, pollen, and shade in these polyculture systems, allowing them to have a greater effect on *T. tabaci* abundance. Predators were also significantly positively correlated with thrips populations despite low abundance of both populations. This relationship could have potential implications for thrips pest management, which are discussed below.

There have been many approaches examined to manage *T. tabaci* in onion over the last several decades. While continued use of insecticides will likely be a major component, novel selective insecticides may be compatible with the conservation of naturally occurring predators in onion production systems. Combining these selective insecticides with thrips-resistant onion cultivars, conservation biological control, and a variety of cultural controls is likely to be the

most sustainable solution for *T. tabaci* management. As we have shown, predators are capable of reducing thrips populations in insecticide-free plots. Conservation of these predators would likely complement and enhance existing insect pest management strategies for *T. tabaci* management.

Furthermore, the exploration of habitat diversification is worthy of pursuit. Typically, habitat diversification schemes are employed to attract and retain predators in agricultural landscapes to improve pest regulation (Altieri and Letourneau 1982, Andow 1991, Landis et al. 2000, Poveda et al. 2008, Letourneau et al. 2011). As we have shown, onion systems in New York are already attracting and retaining predator populations at times when they may have the most impact on thrips management. In insecticide-free plots, predators have a significant negative impact on thrips populations. Further habitat diversification should continue to support and potentially increase predator populations, perhaps even increasing predator diversity by attracting other predators to the onion agroecosystem.

Diversifying the onion agroecosystem in space and time in a way that is compatible with current growing practices is worthy of future investigation. Such strategies may include planting hedgerows or flowering borders to provide resources to beneficial insects or adjusting harvest practices. These diversification strategies and their influence on predator populations may prove to be complementary to our results. Diversification strategies have the potential to also increase all herbivore populations, which may be detrimental to other crops. Furthermore, because *T. tabaci* is a polyphagous species, diversification may introduce potential alternate hosts. However, *T. tabaci* greatly prefers onion to

these alternate hosts and would thus be unlikely to become a pestiferous species on other crops.

Additional benefits of habitat diversification include potentially improved ecological services such as soil fertility, increased crop yield, conservation of pollinating insects, decreased weedy vegetation, and overall agroecosystem stability (Altieri 1999, Gurr et al. 2003). These benefits contribute to the overall stability of the agroecosystem. Outside of the immediate ecosystem, landscape heterogeneity also increases natural enemy and predator populations (Elliott et al. 1999, Thies and Tscharntke 1999, Bianchi et al. 2006, Gardiner et al. 2009, O'Rourke et al. 2010, Chaplin-Kramer et al. 2011). However, reductions in pest populations and crop damage due to landscape diversity have yet to be demonstrated. Furthermore, it is unclear which landscape scale relative to crop area will most impact this relationship. Future studies linking landscape diversity with pest suppression in agricultural settings will greatly contribute to our understanding of the role of landscapes in ecosystems services such as pest control. Further exploration of landscape diversity impact on agroecosystems will likely contribute to conservation-oriented strategies in agricultural pest management.

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